

DECLARATION

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hereby certify that I am conversant in the Japanese and English  
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No. 2002-271968.

Dated this 10th day of September, 2008

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Hirokazu MIYAZONO

JAPAN PATENT OFFICE

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【Document Name】 Specification

【Title of the Invention】 Nitride-Based Semiconductor  
Light-Emitting Device

【Scope of Claim for Patent】

5           【Claim 1】 A nitride-based semiconductor light-  
emitting device comprising:

          a first conductivity type first nitride-based  
semiconductor layer formed on a substrate;

          an active layer, formed on said first nitride-based  
10 semiconductor layer, consisting of a nitride-based  
semiconductor layer;

          a second conductivity type second nitride-based  
semiconductor layer formed on said active layer;

          an undoped contact layer formed on said second  
15 nitride-based semiconductor layer; and

          an electrode formed on said undoped contact layer.

          【Claim 2】 The nitride-based semiconductor light-  
emitting device according to claim 1, wherein

          the band gap of said undoped contact layer is smaller  
20 than the band gap of said second nitride-based  
semiconductor layer.

          【Claim 3】 The nitride-based semiconductor light-  
emitting device according to claim 1 or 2, wherein

          said first conductivity type first nitride-based  
25 semiconductor layer is an n-type first nitride-based

semiconductor layer, and

said second conductivity type second nitride-based semiconductor layer is a p-type second nitride-based semiconductor layer.

5           [Claim 4] The nitride-based semiconductor light-emitting device according to any of claims 1 to 3, wherein said undoped contact layer has a thickness of not more than about 10 nm.

10           [Claim 5] The nitride-based semiconductor light-emitting device according to any of claims 1 to 4, wherein said second conductivity type second nitride-based semiconductor layer includes a second conductivity type cladding layer consisting of AlGaIn.

15           [Claim 6] The nitride-based semiconductor light-emitting device according to any of claims 1 to 5, wherein said undoped contact layer has a band gap larger than the band gap of said active layer.

20           [Claim 7] The nitride-based semiconductor light-emitting device according to any of claims 1 to 6, wherein said undoped contact layer contains InGaIn.

25           [Claim 8] The nitride-based semiconductor light-emitting device according to any of claims 1 to 7, further comprising an undoped third nitride-based semiconductor layer, formed between said active layer and said second conductivity type second nitride-based semiconductor layer,

consisting of a nitride-based semiconductor having a smaller band gap than said second nitride-based semiconductor layer.

[Detailed Description of the Invention]

5           [0001]

[Technical Field to Which the Invention Belongs]

The present invention relates to a nitride-based semiconductor light-emitting device, and more particularly, it relates to a nitride-based semiconductor light-emitting device having nitride-based semiconductor layers formed on a substrate.

[0002]

[Prior Art]

A nitride-based semiconductor light-emitting device such as a nitride-based semiconductor light-emitting diode (LED) or a nitride-based semiconductor laser diode (LD) consisting of  $\text{In}_x\text{Al}_y\text{Ga}_{1-x-y}\text{N}$  ( $0 \leq x$ ,  $0 \leq y$ ,  $x + y \leq 1$ ) has recently been put into practice.

[0003]

20           A conventional nitride-based semiconductor light-emitting device basically has a double heterostructure obtained by successively stacking an n-type nitride-based semiconductor layer consisting of n-type  $\text{Al}_y\text{Ga}_{1-y}\text{N}$  ( $0 \leq y \leq 1$ ), an active layer consisting of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 \leq x \leq 1$ ) and  
25           a p-type nitride-based semiconductor layer consisting of

p-type  $\text{Al}_z\text{Ga}_{1-z}\text{N}$  ( $0 \leq z \leq 1$ ) on a substrate. In general, the nitride-based semiconductor light-emitting device further comprises an n-type contact layer for implementing ohmic contact with an n-side electrode and a p-type  
5 contact layer for implementing ohmic contact with a p-side electrode. A conventional nitride-based semiconductor laser diode may have an n-type optical guide layer and a p-type optical guide layer formed to hold an active layer therebetween.

10           [0004]

The n- or p-type nitride-based semiconductor layer of the aforementioned nitride-based semiconductor light-emitting device is prepared by doping a nitride-based semiconductor with dopants providing n-type carriers  
15 (electrons) or p-type carriers (holes). In order to obtain a nitride-based semiconductor light-emitting device having excellent luminous efficiency, it is inevitably necessary to suppress light absorption in each nitride-based semiconductor layer. However, the activation efficiency of  
20 the dopants for the p-type nitride-based semiconductor is so low that the dopants must be doped in a large quantity in order to obtain a p-type nitride-based semiconductor having prescribed carrier concentration in general. In this case, light absorption is inconveniently increased in  
25 a p-type contact layer or a p-type optical guide layer

having a small band gap due to dopant levels resulting from introduction of the large quantity of dopant in the p-type nitride-based semiconductor. The light absorption is further increased also by crystal defects resulting from the large quantity of dopant.

[0005]

In general, therefore, there is proposed a nitride-based semiconductor laser diode capable of reducing light absorption resulting from the dopants by forming an undoped optical guide layer on an active layer in place of the p-type optical guide layer (See, for example, non-patent document 1).

[0006]

[Non-Patent Document 1]

"Technical Report of IEICE", the Institute of Electronics, Information and Communication Engineers, June 15, 2002, pp. 63-66

[0007]

[Problems to be Solved by the Invention]

However, the aforementioned proposed conventional nitride-based semiconductor laser diode has no countermeasure for preventing a p-type contact layer from light absorption. The p-type contact layer is doped with a large quantity of dopant for implementing ohmic contact with a p-side electrode. Also when light absorption is

reduced in the aforementioned undoped optical guide layer, therefore, it is difficult to inhibit the p-type contact layer from light absorption resulting from the dopants. Consequently, it is disadvantageously difficult to improve  
5 luminous efficiency of the nitride-based semiconductor laser diode. In a nitride-based semiconductor light-emitting diode emitting light through a p-type contact layer, influence exerted on emission characteristics of the nitride-based semiconductor light-emitting device is  
10 disadvantageously increased if light absorption is increased in the p-type contact layer.

[0008]

In order to inhibit a p-type contact layer from light absorption, a p-type nitride-based semiconductor layer  
15 having a large band gap may be employed as the p-type contact layer thereby suppressing light absorption. When the band gap of the p-type contact layer is increased, however, a barrier at the interface between the p-type contact layer and a p-side electrode is so increased that  
20 it is difficult to implement excellent ohmic contact between the p-type contact layer and the p-side electrode. Thus, the nitride-based semiconductor light-emitting device is disadvantageously reduced in luminous efficiency and increased in operation voltage.

25 [0009]

The present invention has been proposed in order to solve the aforementioned problem, and an object of the present invention is to provide a nitride-based semiconductor light-emitting device capable of improving  
5 luminous efficiency by reducing light absorption loss in a contact layer.

[0010]

Another object of the present invention is to further improve the luminous efficiency in the aforementioned  
10 nitride-based semiconductor light-emitting device and reduce an operation voltage.

[0011]

[Means for Solving the Problems]

A nitride-based semiconductor light-emitting device  
15 according to a first aspect of the present invention comprises a first conductivity type first nitride-based semiconductor layer formed on a substrate, an active layer, formed on the first nitride-based semiconductor layer, consisting of a nitride-based semiconductor layer, a  
20 second conductivity type second nitride-based semiconductor layer formed on the active layer, an undoped contact layer formed on the second nitride-based semiconductor layer and an electrode formed on the undoped contact layer. Throughout the specification, the term  
25 "undoped" denotes a state not intentionally doped with a

dopant. Therefore, not only a state doped with absolutely no dopant but also a state unintentionally mixed with a small quantity of dopant corresponds to the term "undoped" in the present invention.

5           [0012]

In the nitride-based semiconductor light-emitting device according to this first aspect, as hereinabove described, the undoped contact layer formed with no dopant levels can be inhibited from light absorption resulting from dopant levels. Further, the undoped contact layer having no crystal defects resulting from doping exhibits excellent crystal quality. Therefore, the undoped contact layer can also be inhibited from light absorption resulting from crystal defects. Thus, light absorption loss in the undoped contact layer can be so reduced that luminous efficiency can be improved.

10  
15

[0013]

In the nitride-based semiconductor light-emitting device according to the aforementioned first aspect, the band gap of the undoped contact layer is preferably smaller than the band gap of the second nitride-based semiconductor layer. According to this structure, the energy barrier is so reduced at the interface between the undoped contact layer and the electrode that ohmic contact between the undoped contact layer and the electrode can be

20  
25

easily implemented. Thus, the luminous efficiency can be further improved and an operation voltage can be reduced.

[0014]

In the aforementioned case, the first conductivity  
5 type first nitride-based semiconductor layer is preferably  
an n-type first nitride-based semiconductor layer, and the  
second conductivity type second nitride-based  
semiconductor layer is preferably a p-type second nitride-  
based semiconductor layer.

10 [0015]

Further, in the aforementioned case, the undoped  
contact layer preferably has a thickness of not more than  
about 10 nm. According to this structure, contact  
resistance between the undoped contact layer and the  
15 electrode can be so reduced that excellent ohmic contact  
can be attained between the undoped contact layer and the  
electrode. Further, resistance of the undoped contact  
layer can be reduced.

[0016]

20 In the aforementioned case, the second conductivity  
type second nitride-based semiconductor layer preferably  
includes a second conductivity type cladding layer  
consisting of AlGaN. According to this structure, the band  
gap of the second nitride-based semiconductor layer can be  
25 so easily increased that light absorption can be reduced

in the second nitride-based semiconductor layer.

[0017]

In the aforementioned case, the undoped contact layer preferably has a band gap larger than the band gap of the active layer. When the active layer is constituted of a single material, the term "the band gap of the active layer" denotes the band gap of the material. When the active layer has a quantum well structure, the term "the band gap of the active layer" denotes the energy gap between two quantum levels (ground states) formed in the conduction band and the valence band. According to this structure, light absorption in the undoped contact layer can be easily reduced. In this case, the undoped contact layer preferably contains InGaN. According to this structure, the band gap of the undoped contact layer can be easily reduced beyond that of the second nitride-based semiconductor layer.

[0018]

In the aforementioned case, the nitride-based semiconductor light-emitting device preferably further comprises an undoped third nitride-based semiconductor layer, formed between the active layer and the second conductivity type second nitride-based semiconductor layer, consisting of a nitride-based semiconductor having a smaller band gap than the second nitride-based

semiconductor layer. According to this structure, the third nitride-based semiconductor layer can control emission characteristics such as optical beam divergence, and can be inhibited from light absorption.

5           [0019]

          [Embodiments of the Invention]

Embodiments of the present invention are now described with reference to the drawings.

          [0020]

10          (First Embodiment)

Fig. 1 is a sectional view showing a nitride-based semiconductor light-emitting diode (blue LED chip) according to a first embodiment of the present invention, and Fig. 2 is a top plan view of the nitride-based semiconductor light-emitting diode according to the first embodiment shown in Fig. 1. The structure of a nitride-based semiconductor light-emitting diode according to a first embodiment of the present invention is described with reference to Figs. 1 and 2.

20          [0021]

In the nitride-based semiconductor light-emitting diode according to the first embodiment, a low-temperature buffer layer 2 of AlGa<sub>N</sub> having a thickness of about 10 nm is formed on the (0001) plane of a sapphire substrate 1, as shown in Fig. 1. The sapphire substrate 1 is an example

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of the "substrate" in the present invention. A high-temperature buffer layer 3 of undoped GaN having a thickness of about 1  $\mu\text{m}$  is formed on the low-temperature buffer layer 2. An n-type contact layer 4 of n-type GaN doped with Si having a thickness of about 5  $\mu\text{m}$  is formed on the high-temperature buffer layer 3. The n-type contact layer 4 is partially removed to have a projecting portion. The n-type contact layer 4 also serves as an n-type cladding layer. The n-type contact layer 4 is an example of the "first nitride-based semiconductor layer" in the present invention.

[0022]

An MQW active layer 5 having a multiple quantum well (MQW) structure formed by stacking six barrier layers 5a of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  each having a thickness of about 5 nm and five well layers 5b of undoped  $\text{In}_{0.35}\text{Ga}_{0.65}\text{N}$  each having a thickness of about 5 nm is formed to be substantially entirely in contact with the upper surface of the projecting portion of the n-type contact layer 4. The MQW active layer 5 is an example of the "active layer" in the present invention. A protective layer 6 of undoped GaN having a thickness of about 10 nm is formed on the MQW active layer 5. The protective layer 6 has a function of preventing In atoms in the MQW active layer 5 from desorption thereby preventing the MQW active layer 5 from

deterioration of crystal quality.

[0023]

According to the first embodiment, a p-type cladding layer 7 of p-type  $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$  doped with Mg having an atomic density of about  $3 \times 10^{19} \text{ cm}^{-3}$  and a carrier concentration of about  $1 \times 10^{18} \text{ cm}^{-3}$  is formed on the protective layer 6 with a thickness of about 0.15  $\mu\text{m}$ . The p-type cladding layer 7 is an example of the "second nitride-based semiconductor layer" or the "cladding layer" in the present invention. According to the first embodiment, further, an undoped contact layer 8 of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  having a thickness of about 10 nm is formed on the p-type cladding layer 7. The band gap of the undoped contact layer 8 consisting of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  is smaller than the band gap of the p-type cladding layer 7 consisting of p-type  $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$  and larger than the band gap of the MQW active layer 5 consisting of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  and undoped  $\text{In}_{0.35}\text{Ga}_{0.65}\text{N}$ . The term "the band gap of the MQW active layer 5" denotes the energy gap between two quantum levels (ground states) formed in the conduction band and the valence band. The energy gap between the quantum levels of the MQW active layer 5 constituted of  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  and  $\text{In}_{0.35}\text{Ga}_{0.65}\text{N}$  is smaller than the band gap of the undoped contact layer 8 consisting of  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$ .

[0024]

Fig. 3 is a graph showing the relationship between the thickness of the contact layer consisting of various materials and contact resistance value. This graph shows relative contact resistance values with reference to a contact layer formed by a p-type GaN layer doped with Mg having a carrier concentration of about  $1 \times 10^{18} \text{ cm}^{-3}$ . p-type GaN doped with Mg is a standard material for a contact layer.

[0025]

As shown in Fig. 3, it is understood possible to approach the contact resistance of the undoped contact layer 8 consisting of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  to that of the p-type contact layer consisting of p-type GaN doped with Mg by setting the thickness thereof to not more than about 10 nm. It is also understood possible to reduce the contact resistance of an undoped contact layer consisting of undoped GaN to some extent by setting the thickness thereof to not more than about 10 nm. However, the contact resistance of the undoped contact layer 8 consisting of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  can be more reduced as compared with the undoped contact layer consisting of undoped GaN. According to the first embodiment, the undoped contact layer 8 of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  having the thickness of not more than about 10 nm is employed in consideration of the

aforementioned point. It is understood that an undoped contact layer consisting of undoped  $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$  still exhibits large contact resistance also when the thickness thereof is set to not more than about 10 nm. It is further understood that a p-type contact layer consisting of p-type  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  exhibits high contact resistance of about ten times that of the p-type contact layer consisting of p-type GaN.

[0026]

As shown in Figs. 1 and 2, the interdigital p-side electrode 9 constituted of the Pd film having the thickness of about 100 nm and the Au film having the thickness of about 100 nm in ascending order is formed on the upper surface of the undoped contact layer 8. The p-side electrode 9 is an example of the "electrode" in the present invention. The p-side pad electrode 10 constituted of the Ti film having the thickness of about 30 nm and the Au film having the thickness of about 500 nm in ascending order is formed on the partial region of the upper surface of the p-side electrode 9. Further, the n-side electrode 11 of Al having the thickness of about 500 nm is formed on the partial region other than a projecting portion of the surface of the n-type contact layer 4.

[0027]

According to the first embodiment, as hereinabove

described, the undoped contact layer 8 formed with no dopant levels can be prevented from light absorption resulting from dopant levels. Further, the undoped contact layer 8 having no crystal defects resulting from doping has excellent crystal quality. Therefore, the undoped contact layer 8 can be inhibited also from light absorption resulting from crystal defects. Thus, light absorption loss in the undoped contact layer 8 can be so reduced that the nitride-based semiconductor light-emitting diode can be improved in luminous efficiency.

[0028]

According to the first embodiment, further, the band gap of the undoped contact layer 8 is rendered smaller than that of the p-type cladding layer 7 as hereinabove described to reduce the energy barrier at the interface between the undoped contact layer 8 and the p-side electrode 9, whereby ohmic contact can be easily implemented between the undoped contact layer 8 and the p-side electrode 9. Thus, the nitride-based semiconductor light-emitting diode can be further improved in luminous efficiency and reduced in operation voltage.

[0029]

According to the first embodiment, in addition, the thickness of the undoped contact layer 8 is so set to not more than about 10 nm that the contact resistance between

the undoped contact layer 8 and the p-side electrode 9 can be reduced, whereby excellent ohmic contact can be attained between the undoped contact layer 8 and the p-side electrode 9. Further, the resistance of the undoped  
5 contact layer 8 can be reduced.

[0030]

According to the first embodiment, further, the p-type cladding layer 7 is prepared from p-type  $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$  doped with Mg as hereinabove described so that the band  
10 gap thereof can be easily increased for reducing light absorption in the p-type cladding layer 7. According to the first embodiment, in addition, the undoped contact layer 8 is prepared from  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  so that the band gap thereof can be easily reduced beyond that of the p-type  
15 cladding layer 7. Further, the band gap of the undoped contact layer 8 is larger than that of the MQW active layer 5 as hereinabove described, whereby light absorption in the undoped contact layer 8 can be easily reduced.

[0031]

20 Figs. 4 and 5 are sectional views for illustrating a process of fabricating the nitride-based semiconductor light-emitting diode according to the first embodiment shown in Figs. 1 and 2. A process of fabricating the nitride-based semiconductor light-emitting diode according  
25 to the first embodiment is now described with reference to

Figs. 1, 2, 4 and 5.

[0032]

As shown in Fig. 4, the low-temperature buffer layer 2, the high-temperature buffer layer 3, the n-type contact layer 4, the MQW active layer 5, the protective layer 6, the p-type cladding layer 7 and the undoped contact layer 8 are successively grown on the sapphire substrate 1 by MOVPE (metal organic vapor phase epitaxy).

[0033]

More specifically, the low-temperature buffer layer 2 of AlGaN having the thickness of about 10 nm is grown on the (0001) plane of the sapphire substrate 1 held at a non-single-crystal growth temperature of about 600°C with carrier gas consisting of H<sub>2</sub> and N<sub>2</sub> (H<sub>2</sub>: about 50 %) and material gas consisting of NH<sub>3</sub>, trimethyl aluminum (TMA1) and trimethyl gallium (TMGa).

[0034]

Then, the sapphire substrate 1 is held at a single-crystal growth temperature of about 1150°C for growing the high-temperature buffer layer 3 of undoped GaN having the thickness of about 1 μm on the low-temperature buffer layer 2 at a growth rate of about 1 μm/h. with carrier gas consisting of H<sub>2</sub> and N<sub>2</sub> (H<sub>2</sub>: about 50 %) and material gas consisting of NH<sub>3</sub> and TMGa.

[0035]

Then, the sapphire substrate 1 is held at a single-crystal growth temperature of about 1150°C for growing the n-type contact layer 4 of n-type GaN doped with Si having the thickness of about 5 μm on the high-temperature buffer layer 3 at a growth rate of about 3 μm/h. with carrier gas consisting of H<sub>2</sub> and N<sub>2</sub> (H<sub>2</sub>: about 50 %), material gas consisting of NH<sub>3</sub> and TMGa and dopant gas consisting of SiH<sub>4</sub>.

[0036]

Then, the sapphire substrate 1 is held at a single-crystal growth temperature of about 850°C for alternately growing the six barrier layers 5a of undoped In<sub>0.15</sub>Ga<sub>0.85</sub>N each having the thickness of about 5 nm and the five well layers 5b of undoped In<sub>0.35</sub>Ga<sub>0.65</sub>N each having the thickness of about 5 nm on the n-type contact layer 4 at a growth rate of about 0.4 nm/s. with carrier gas consisting of H<sub>2</sub> and N<sub>2</sub> (H<sub>2</sub>: about 1 % to about 5 %) and material gas consisting of NH<sub>3</sub>, triethyl gallium (TEGa) and trimethyl indium (TMin). Thus, the MQW active layer 5 is formed on the n-type contact layer 4. Then, the protective layer 6 of undoped GaN having the thickness of about 10 nm is grown on the MQW active layer 5 at a growth rate of about 0.4 nm/s.

[0037]

Then, the sapphire substrate 1 is held at a single-

crystal growth temperature of about 1150°C for growing the p-type cladding layer 7 of p-type  $\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}$  doped with Mg having the atomic density of about  $3 \times 10^{19} \text{ cm}^{-3}$  and the carrier concentration of about  $1 \times 10^{18} \text{ cm}^{-3}$  on the protective layer 6 with the thickness of about 0.15  $\mu\text{m}$  at a growth rate of about 3  $\mu\text{m/h}$ . with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 1 % to about 3 %), material gas consisting of  $\text{NH}_3$ , TMGa and TMAI and dopant gas consisting of cyclopentadienyl magnesium ( $\text{Cp}_2\text{Mg}$ ).

[0038]

At this time, Mg serving as a dopant can be activated by reducing the  $\text{H}_2$  composition of the carrier gas to about 1 % to 3 %, whereby the p-type cladding layer 7 can be formed with the high carrier concentration.

[0039]

Then, the sapphire substrate 1 is held at a single-crystal growth temperature of about 850°C for growing the undoped contact layer 8 of undoped  $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$  having the thickness of not more than about 10 nm on the p-type cladding layer 7 at a growth rate of about 3  $\mu\text{m/h}$ . with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 1 % to about 5 %) and material gas consisting of  $\text{NH}_3$ , TEGa and TMIn.

[0040]

As shown in Fig. 5, partial regions of the undoped contact layer 8, the p-type cladding layer 7, the

protective layer 6, the MQW layer 5 and the n-type contact layer 4 are removed by reactive ion beam etching (RIBE) or the like, thereby exposing the remaining partial region of the n-type contact layer 4.

5           [0041]

As shown in Figs. 1 and 2, the interdigital p-side electrode 9 constituted of the Pd film having the thickness of about 100 nm and the Au film having the thickness of about 100 nm in ascending order is formed on the upper surface of the undoped contact layer 8 by vacuum evaporation or the like. The p-side pad electrode 10 constituted of the Ti film having the thickness of about 30 nm and the Au film having the thickness of about 500 nm in ascending order is formed on the partial region of the upper surface of the p-side electrode 9. Further, the n-side electrode 11 of Al having the thickness of about 500 nm is formed on the exposed surface of the n-type contact layer 4.

          [0042]

20           Thereafter heat treatment is performed at a temperature of about 600°C, thereby bringing the p-side electrode 9 and the n-side electrode 11 into ohmic contact with the undoped contact layer 8 and the n-type contact layer 4 respectively.

25           [0043]

Finally, element isolation is performed for obtaining a substantially square chip having edges of about 400  $\mu\text{m}$ , for example, by scribing, dicing or braking. Thus, the nitride-based semiconductor light-emitting diode according to the first embodiment is fabricated.

[0044]

An LED lamp including a blue LED chip according to the first embodiment may be prepared by mounting the nitride-based semiconductor light-emitting diode (blue LED chip) according to the first embodiment fabricated in the aforementioned manner to a frame (not shown) and hardening resin at a temperature of about 200°C to cover the blue LED chip and the frame.

[0045]

(Second Embodiment)

Fig. 6 is a sectional view showing a nitride-based semiconductor laser diode (LD chip) according to a second embodiment of the present invention. Referring to Fig. 6, a second embodiment of the present invention is applied to a nitride-based semiconductor laser diode dissimilarly to the first embodiment applied to the nitride-based semiconductor light-emitting diode.

[0046]

In the nitride-based semiconductor laser diode according to the second embodiment, an n-type GaN layer

doped with Si having a thickness of about 1  $\mu\text{m}$  is formed on an n-type GaN substrate 21 doped with oxygen having a surface of the (0001) Ga plane, as shown in Fig. 6. An n-type cladding layer 23 of n-type  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  doped with Si having a thickness of about 1  $\mu\text{m}$  is formed on the n-type GaN layer 22. The n-type GaN substrate 21 is an example of the "substrate" in the present invention, and the n-type GaN layer 22 and the n-type cladding layer 23 are examples of the "first nitride-based semiconductor layer" in the present invention.

[0047]

An n-type optical guide layer 24 of n-type GaN having a thickness of about 100 nm is formed on the n-type cladding layer 23. An MQW active layer 25 having a multiple quantum well structure obtained by alternately stacking four barrier layers 25a of undoped  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$  each having a thickness of about 15 nm and three well layers 25b of undoped  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  each having a thickness of about 4 nm is formed on the n-type optical guide layer 24.

[0048]

According to the second embodiment, a protective layer 26 of undoped  $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$  having a thickness of about 20 nm is formed on the MQW active layer 25. This protective layer 26 has a function of preventing In atoms in the MQW active layer 25 from desorption thereby

preventing the MQW active layer 25 from deterioration of crystal quality. An optical guide layer 27 of undoped GaN having a thickness of about 100 nm is formed on the protective layer 26. The optical guide layer 27 of undoped  
5 GaN has a band gap smaller than that of a p-type cladding layer 28 of  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  described later. The optical guide layer 27 is an example of the "third nitride-based semiconductor layer" in the present invention.

[0049]

10 The p-type cladding layer 28 of  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  doped with Mg having a thickness of about 280 nm with a striped projecting portion (ridge portion) of about 1.5  $\mu\text{m}$  in width around its central portion is formed on the optical guide layer 27. The p-type cladding layer 28 is an example  
15 of the "second nitride-based semiconductor layer" or the "cladding layer" in the present invention.

[0050]

According to the second embodiment, an undoped contact layer 29 of undoped  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$  having a thickness  
20 of about 5 nm is formed on the projecting portion of the p-type cladding layer 28 consisting of  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ . The band gap of the undoped contact layer 29 is smaller than that of the p-type cladding layer 28 and larger than that of the MQW active layer 25. The term "the band gap of the  
25 MQW active layer 25" denotes the energy gap between two

quantum levels (ground states) formed in the conduction band and the valence band. The energy gap between the quantum levels of the MQW active layer 25 constituted of  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$  and  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  is smaller than the band gap of the undoped contact layer 29 consisting of  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$ .

[0051]

An insulator film 30 of  $\text{SiO}_2$  is formed to cover the surface of the p-type cladding layer 28 and the side surfaces of the undoped contact layer 29. A p-side electrode 31 constituted of a Pd film, a Pt film and an Au film in ascending order is formed on the undoped contact layer 29. The p-side electrode 31 is an example of the "electrode" in the present invention. A p-side pad electrode 32 is formed to cover the surfaces of the insulator film 30 and the p-side electrode 31. An n-side electrode 33 constituted of a Ti film, a Pt film and an Au film from the side closer to the back surface of the n-type GaN substrate 21 is formed on the back surface of the n-type GaN substrate 21.

[0052]

According to the second embodiment, as hereinabove described, the undoped contact layer 29 formed with no dopant levels can be prevented from light absorption resulting from dopant levels. Further, the undoped contact layer 29 having no crystal defects resulting from doping

exhibits excellent crystal quality. Therefore, the undoped contact layer 29 can also be inhibited from light absorption resulting from crystal defects. Thus, light absorption loss in the undoped contact layer 29 can be so reduced that the nitride-based semiconductor laser diode can be improved in luminous efficiency.

[0053]

According to the second embodiment, further, the band gap of the undoped contact layer 29 is rendered smaller than that of the p-type cladding layer 28 as hereinabove described to reduce the energy barrier at the interface between the undoped contact layer 29 and the p-side electrode 31, whereby ohmic contact can be easily implemented between the undoped contact layer 29 and the p-side electrode 31.

[0054]

According to the second embodiment, in addition, the p-type cladding layer 28 is constituted of p-type  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  doped with Mg as hereinabove described so that the band gap thereof can be easily increased for reducing light absorption in the p-type cladding layer 28. According to the second embodiment, further, the undoped contact layer 29 is prepared from  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$  so that the band gap thereof can be easily reduced beyond that of the p-type cladding layer 28. Further, the band gap of the

undoped contact layer 29 is larger than that of the MQW active layer 25 as hereinabove described, whereby light absorption in the undoped contact layer 29 can be easily reduced.

5           [0055]

According to the second embodiment, further, the undoped optical guide layer 27 having the band gap smaller than that of the p-type cladding layer 28 is provided between the MQW active layer 25 and the p-type cladding layer 28 as hereinabove described, whereby the optical guide layer 27 can control emission characteristics such as optical beam divergence, and can be inhibited from light absorption.

          [0056]

15           Figs. 7 to 9 are sectional views for illustrating a process of fabricating the nitride-based semiconductor laser diode according to the second embodiment shown in Fig. 6. A process of fabricating the nitride-based semiconductor laser diode according to the second embodiment is now described with reference to Figs. 6 to 9.

          [0057]

As shown in Fig. 7, the n-type GaN layer 22, the n-type cladding layer 23, the n-type optical guide layer 24, the MQW active layer 25, the protective layer 26, the optical guide layer 27, the p-type cladding layer 28 and

the undoped contact layer 29 are successively grown on the n-type GaN substrate 21 doped with oxygen having the surface of the (0001) Ga plane by MOVPE.

[0058]

5           More specifically, the n-type GaN substrate 21 is held at a growth temperature of about 1150°C for growing the n-type GaN layer 22 doped with Si having the thickness of about 1  $\mu\text{m}$  on the n-type GaN substrate 21 doped with oxygen having the surface of the (0001) Ga plane at a  
10 growth rate of about 3  $\mu\text{m}/\text{h}$ . with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 50 %), material gas consisting of  $\text{NH}_3$  and TMGa and dopant gas consisting of  $\text{SiH}_4$ .

[0059]

15           Then, the n-type GaN substrate 21 is held at a growth temperature of about 1150°C for growing the n-type cladding layer 23 of n-type  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  doped with Si having the thickness of about 1  $\mu\text{m}$  on the n-type GaN layer 22 at a growth rate of about 3  $\mu\text{m}/\text{h}$ . with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 50 %), material gas consisting of  
20  $\text{NH}_3$ , TMGa and TMAI and dopant gas consisting of  $\text{SiH}_4$ . Then, the n-type optical guide layer 24 of n-type GaN having the thickness of about 100 nm is grown on the n-type cladding layer 23 at a growth rate of about 3  $\mu\text{m}/\text{h}$ .

[0060]

25           Then, the n-type GaN substrate 21 is held at a growth

temperature of about 850°C for alternately growing the four barrier layers 25a of undoped  $\text{In}_{0.05}\text{Ga}_{0.95}\text{N}$  each having the thickness of about 15 nm and the three well layers 25b of undoped  $\text{In}_{0.1}\text{Ga}_{0.9}\text{N}$  each having the thickness of about 4 nm on the n-type optical guide layer 24 at a growth rate of about 0.4 nm/s. with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 1 % to about 5 %) and material gas consisting of  $\text{NH}_3$ ,  $\text{TEGa}$  and  $\text{TMin}$ . Thus, the MQW active layer 25 is formed on the n-type optical guide layer 24. Then, the protective layer 26 of undoped  $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$  having the thickness of about 20 nm is grown on the MQW active layer 25 at a growth rate of about 0.4 nm/s.

[0061]

Then, the n-type GaN substrate 21 is held at a growth temperature of about 1150°C for growing the optical guide layer 27 of undoped GaN having the thickness of about 100 nm on the protective layer 26 at a growth rate of about 3  $\mu\text{m}/\text{h}$ . with carrier gas consisting of  $\text{H}_2$  and  $\text{N}_2$  ( $\text{H}_2$ : about 1 % to about 3 %) and material gas consisting of  $\text{NH}_3$  and  $\text{TMGa}$ . Material gas consisting of  $\text{TMAI}$  as well as dopant gas consisting of  $\text{Cp}_2\text{Mg}$  are further added for growing the p-type cladding layer 28 of p-type  $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$  doped with Mg having the thickness of about 280 nm on the optical guide layer 27 at a growth rate of about 3  $\mu\text{m}/\text{h}$ .

[0062]

At this time, Mg serving as a dopant can be activated by reducing the H<sub>2</sub> composition of the carrier gas to about 1 % to 3 %, whereby the p-type cladding layer 28 can be formed with the high carrier concentration.

5           [0063]

Then, the n-type GaN substrate 21 is held at a growth temperature of about 850°C for growing the undoped contact layer 29 of undoped In<sub>0.05</sub>Ga<sub>0.95</sub>N having the thickness of about 5 nm on the p-type cladding layer 28 at a growth  
10 rate of about 3 μm/h with carrier gas consisting of H<sub>2</sub> and N<sub>2</sub> (H<sub>2</sub>: about 1 % to about 5 %) and material gas consisting of NH<sub>3</sub>, TEGa and TMin.

          [0064]

As shown in Fig. 8, the p-side electrode 31  
15 constituted of the Pd film, the Pt film and the Au film in ascending order is formed on a portion around the center of the undoped contact layer 29 by vacuum evaporation and lithography in a striped manner with the width of about 1.5 μm.

20           [0065]

Thereafter partial regions of the undoped contact layer 29 and the p-type cladding layer 28 are removed by reactive ion beam etching or the like, as shown in Fig. 9. Thus, the projecting portion (ridge portion) is formed to  
25 serve as a current injection region.

[0066]

Then, an insulator film (not shown) of  $\text{SiO}_2$  is formed to cover the surfaces of the p-type cladding layer 28, the undoped contact layer 29 and the p-side electrode 31 by plasma CVD (chemical vapor deposition) and thereafter partially removed from the surface of the p-side electrode 31, thereby obtaining the insulator film 30 in the shape shown in Fig. 6. The p-side pad electrode 32 is formed to cover the surfaces of the insulator film 30 and the p-side electrode 31.

[0067]

Finally, the n-type GaN substrate 21 is polished to a prescribed thickness of about 100  $\mu\text{m}$ , for example, and the n-side electrode 33 constituted of the Ti film, the Pt film and the Au film from the side closer to the back surface of the n-type GaN substrate 21 is thereafter formed on the back surface of the n-type GaN substrate 21. Thus, the nitride-based semiconductor laser diode according to the second embodiment is formed.

[0068]

(Third Embodiment)

Fig. 10 is a sectional view showing a nitride-based semiconductor light-emitting diode (blue LED chip) according to a third embodiment of the present invention. Referring to Fig. 10, a nitride-based semiconductor light-

emitting diode according to a third embodiment of the present invention is formed with an undoped GaN layer 44 having a lower dislocation density in place of the high-temperature buffer layer 3 formed in the aforementioned first embodiment. The remaining structure of the third  
5 embodiment is similar to that of the first embodiment.

[0069]

In the nitride-based semiconductor light-emitting diode according to the third embodiment, mask layers 42 of  
10 SiN each having a thickness of about 10 nm to about 1000 nm with an inverted mesa (inverted trapezoidal) section are formed on the (0001) plane of a sapphire substrate 41 in a striped (elongated) manner with a cycle of about 7  $\mu\text{m}$ . The sapphire substrate 41 is an example of the "substrate"  
15 in the present invention. The mask layers 42 are so formed that the minimum distance between adjacent ones of the mask layers 42 is smaller than the width of the portions of the sapphire substrate 42 exposed between the mask  
layers 42.

20 [0070]

Low-temperature buffer layers 43 of AlGa<sub>N</sub> or Ga<sub>N</sub> having a thickness of about 10 nm to about 50 nm are formed on the portions of the sapphire substrate 41 exposed between the mask layers 42. The low-dislocation  
25 undoped GaN layer 44 having a thickness of about 2  $\mu\text{m}$  is

formed on the low-temperature buffer layers 43 and the mask layers 42 by selective lateral growth to fill up the clearances between the mask layers 42.

[0071]

5           An n-type contact layer 4, an MQW active layer 5, a protective layer 6, a p-type cladding layer 7, an undoped contact layer 8, a p-side electrode 9, a p-side pad electrode 10 and an n-side electrode 11 formed on the undoped GaN layer 44 are similar in thickness and  
10           composition to those of the first embodiment shown in Fig. 1.

[0072]

          According to the third embodiment, the nitride-based semiconductor layers 4 to 8 formed on the undoped GaN  
15           layer 44 having a lower dislocation density than the high-temperature buffer layer 3 (see Fig. 1) according to the first embodiment can be further inhibited from formation of crystal defects. Thus, the nitride-based semiconductor layers 4 to 8 can be formed with smaller numbers of  
20           crystal defects, to be further inhibited from light absorption resulting from crystal defects. Consequently, a blue LED chip having higher luminous efficiency can be fabricated.

[0073]

25           The remaining effects of the third embodiment are

similar to those of the first embodiment.

[0074]

Figs. 11 to 13 are sectional views for illustrating a process of fabricating the nitride-based semiconductor light-emitting diode according to the third embodiment shown in Fig. 10. A process of fabricating the nitride-based semiconductor light-emitting diode according to the third embodiment is now described with reference to Figs. 10 to 13.

[0075]

As shown in Fig. 11, an SiN film (not shown) is formed on the overall surface of the sapphire substrate 41, and photoresist layers (not shown) are thereafter formed on prescribed regions of the SiN film. The photoresist layers are employed as masks for wet-etching the SiN film, thereby forming the striped mask layers 42. The mask layers 42 are in the form of inverted mesas (inverted trapezoids) having overhangs 42a. Openings of the mask layers 42 are preferably formed in the [11-20] direction or the [1-100] direction of the sapphire substrate 41, for example. Thereafter the low-temperature buffer layers 43 of AlGaN or GaN having the thickness of about 10 nm to about 50 nm are grown on the portions of the sapphire substrate 41 exposed between the mask layers 42 at a growth temperature of about 500°C to about 700°C.

[0076]

Then, the mask layers 42 are employed as selective growth masks for laterally growing the undoped GaN layer 44 (see Fig. 13) on the low-temperature buffer layers 43 by MOVPE or HVPE (hydride vapor phase epitaxy) at a growth temperature of about 950°C to about 1200°C. In this case, the undoped GaN layer 44 is first upwardly grown on the exposed upper surfaces of the low-temperature buffer layers 43. Thus, undoped GaN layers 44a of a facet structure having triangular sections are grown around the centers of the clearances between the mask layers 42 in the initial growth stage, as shown in Fig. 12. Further, undoped GaN layers 44b of a facet structure smaller than the undoped GaN layers 44a are formed under the overhangs 42a. These undoped GaN layers 44a and 44b are further laterally grown also on the mask layers 42, to coalesce into the undoped GaN layer 44. Thus, the undoped GaN layer 44 having an upper surface consisting of a flat continuous film is formed with the thickness of about 2  $\mu\text{m}$ .

[0077]

Thus, the undoped GaN layer 44 is laterally grown from the initial growth stage, whereby dislocations formed therein are laterally bent from the initial growth stage. Consequently, the undoped GaN layer 44 can be formed with a smaller thickness and a dislocation density reduced to

about  $7 \times 10^7 \text{ cm}^{-2}$ .

[0078]

Thereafter the n-type contact layer 4, the MQW active layer 5, the protective layer 6, the p-type cladding layer 7 and the undoped contact layer 8 are successively formed on the undoped GaN layer 44 as shown in Fig. 10 through a fabrication process similar to that in the first embodiment, and the n-type contact layer 4 through the undoped contact layer 8 are partially removed. The p-side electrode 9 and the p-side pad electrode 10 are successively formed on the undoped contact layer 8. Thereafter the n-side electrode 11 is formed on the exposed surface of the n-type contact layer 4.

[0079]

Finally, element isolation is performed for obtaining a substantially square chip having edges of about 400  $\mu\text{m}$ , for example, by scribing, dicing or braking. Thus, the nitride-based semiconductor light-emitting diode according to the third embodiment is fabricated.

[0080]

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of

the appended claims.

[0081]

For example, while the sapphire substrate 1 or 41 or the n-type GaN substrate 21 is employed as the substrate in each of the aforementioned first to third embodiments, the present invention is not restricted to this but a spinel substrate, a silicon substrate, an SiC substrate, a GaAs substrate, a GaP substrate, an InP substrate, a quartz substrate, a ZrB<sub>2</sub> substrate or the like may alternatively be employed.

[0082]

While the undoped contact layer consists of a single layer of undoped InGa<sub>N</sub> in each of the aforementioned first to third embodiments, the present invention is not restricted to this but a layer consisting of InGa<sub>N</sub> or the like having a band gap larger than that of an active layer may alternatively be formed in a superlattice including at least a single layer. For example, the superlattice structure may conceivably be formed by stacking a layer of In<sub>x</sub>Ga<sub>1-x</sub>N having a thickness of several nm and a layer of In<sub>y</sub>Ga<sub>1-y</sub>N ( $X > Y > 0$ ) having a thickness of several nm or stacking a layer of InGa<sub>N</sub> having a thickness of several nm and a layer of AlGa<sub>N</sub> (including Ga<sub>N</sub>) having a thickness of several nm.

[0083]

While the nitride-based semiconductor layers are so stacked that the surfaces thereof are along the (0001) planes in each of the aforementioned first to third embodiments, the present invention is not restricted to this but the nitride-based semiconductor layers may alternatively be stacked along other orientations. For example, these layers may alternatively be stacked so that the surfaces thereof are along the (H, K, -H-K, 0) planes such as the (1-100) planes or the (11-20) planes. In this case, no piezoelectric field is generated in the MQW active layer 5 or 25 and hence a recombination probability of holes and electrons can be inhibited from reduction resulting from inclination of energy bands of the well layers 5b or 25b. Consequently, the MQW active layer 5 or 25 can be improved in luminous efficiency.

[0084]

While the active layer 5 or 25 is in the multiple quantum well (MQW) structure in each of the aforementioned first to third embodiments, the present invention is not restricted to this but a thick single active layer having no quantum effect or an active layer of a single quantum well structure can also attain similar effects.

[0085]

[Effect of the Invention]

As hereinabove described, according to the present

invention, a nitride-based semiconductor device capable of improving luminous efficiency by reducing light absorption loss in a contact layer can be provided.

[BRIEF DESCRIPTION OF THE DRAWINGS]

5           [Fig. 1]

A sectional view showing a nitride-based semiconductor light-emitting diode (blue LED chip) according to a first embodiment of the present invention;

          [Fig. 2]

10           A top plan view of the nitride-based semiconductor light-emitting diode according to the first embodiment shown in Fig. 1;

          [Fig. 3]

          A graph showing the relationship between the  
15           thickness of the contact layer consisting of various materials and contact resistance value according to the first embodiment shown in Fig. 1;

          [Fig. 4]

          A sectional view for illustrating a process of  
20           fabricating the nitride-based semiconductor light-emitting diode according to the first embodiment shown in Figs. 1 and 2;

          [Fig. 5]

          A sectional view for illustrating a process of  
25           fabricating the nitride-based semiconductor light-emitting

diode according to the first embodiment shown in Figs. 1 and 2;

[Fig. 6]

A sectional view showing a nitride-based semiconductor laser diode (LD chip) according to a second embodiment of the present invention;

[Fig. 7]

A sectional view for illustrating a process of fabricating the nitride-based semiconductor laser diode according to the second embodiment shown in Fig. 6;

[Fig. 8]

A sectional view for illustrating a process of fabricating the nitride-based semiconductor laser diode according to the second embodiment shown in Fig. 6;

[Fig. 9]

A sectional view for illustrating a process of fabricating the nitride-based semiconductor laser diode according to the second embodiment shown in Fig. 6;

[Fig. 10]

A sectional view showing a nitride-based semiconductor light-emitting diode (blue LED chip) according to a third embodiment of the present invention;

[Fig. 11]

A sectional view for illustrating a process of fabricating the nitride-based semiconductor light-emitting

diode according to the third embodiment shown in Fig. 10;  
[Fig. 12]

A sectional view for illustrating a process of  
fabricating the nitride-based semiconductor light-emitting  
5 diode according to the third embodiment shown in Fig. 10;  
[Fig. 13]

A sectional view for illustrating a process of  
fabricating the nitride-based semiconductor light-emitting  
diode according to the third embodiment shown in Fig. 10.

10 [Description of Reference Numerals]

- 1, 41 sapphire substrate (substrate)
- 4 n-type contact layer (first nitride-based semiconductor layer)
- 5, 25 MQW active layer (active layer)
- 15 7, 28 p-type cladding layer (second nitride-based semiconductor layer, cladding layer)
- 8, 29 undoped contact layer
- 9, 31 p-side electrode (electrode)
- 21 n-type GaN substrate (substrate)
- 20 22 n-type GaN layer (first nitride-based semiconductor layer)
- 23 n-type cladding layer (first nitride-based semiconductor layer)
- 24 n-type optical guide layer 24
- 25 27 optical guide layer (third nitride-based

semiconductor layer)

FIG.1

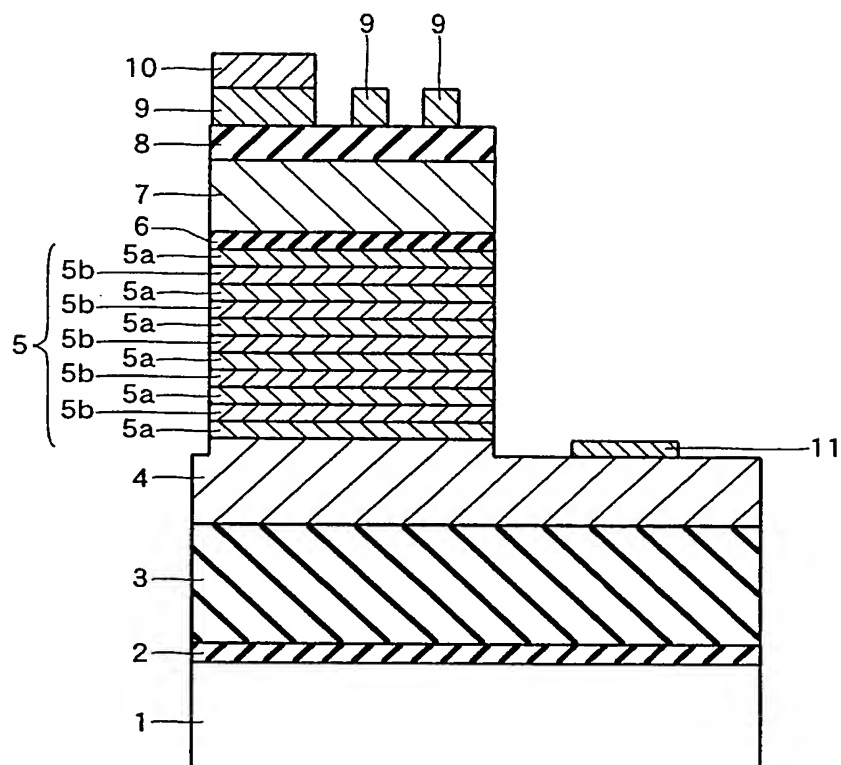


FIG.2

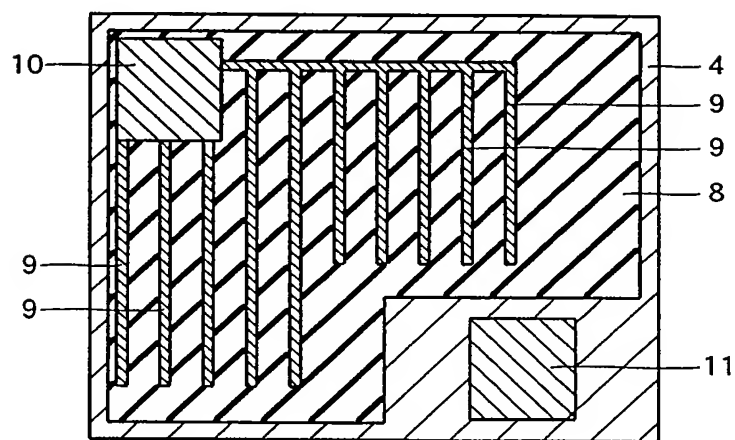


FIG.3

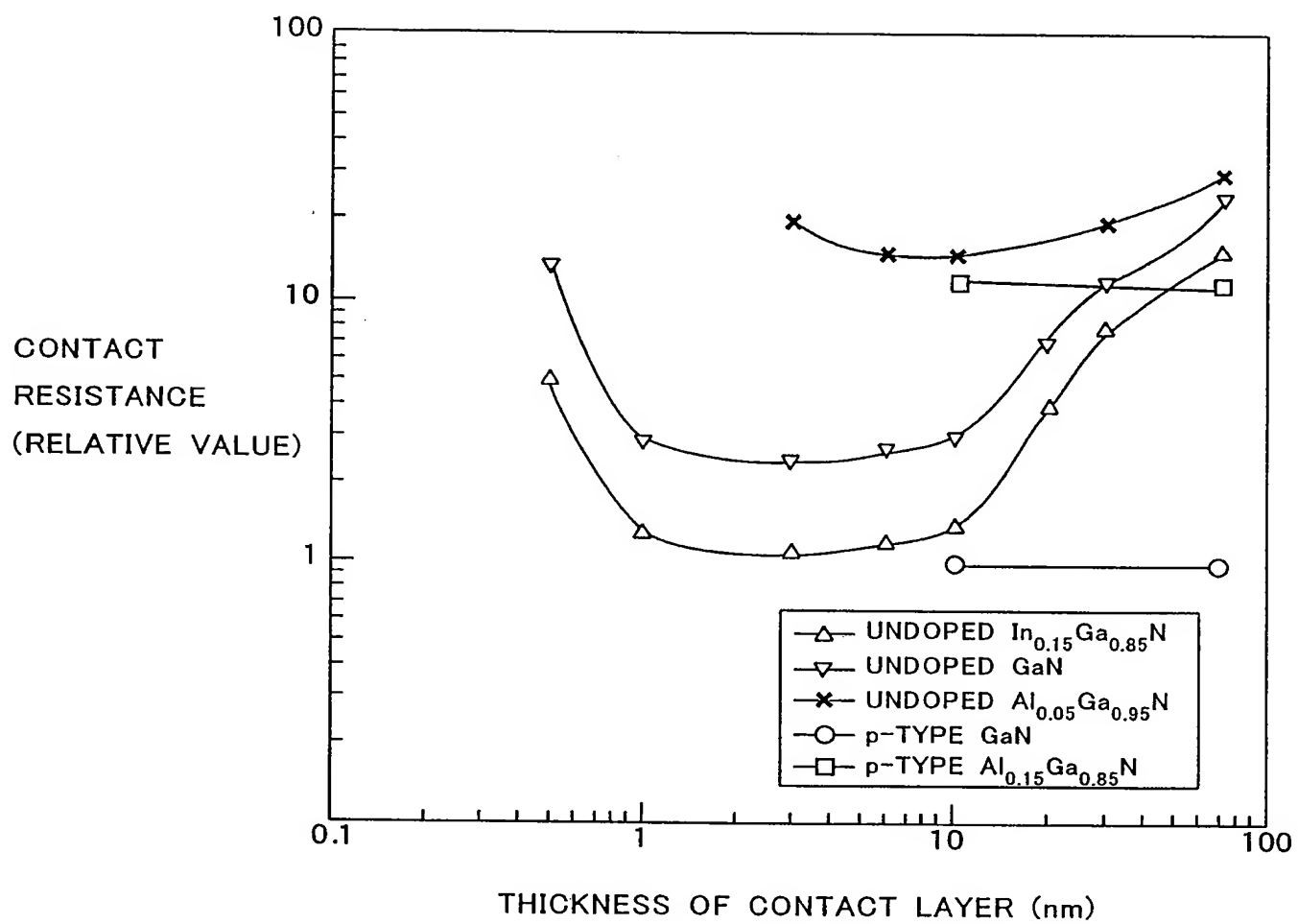


FIG.4

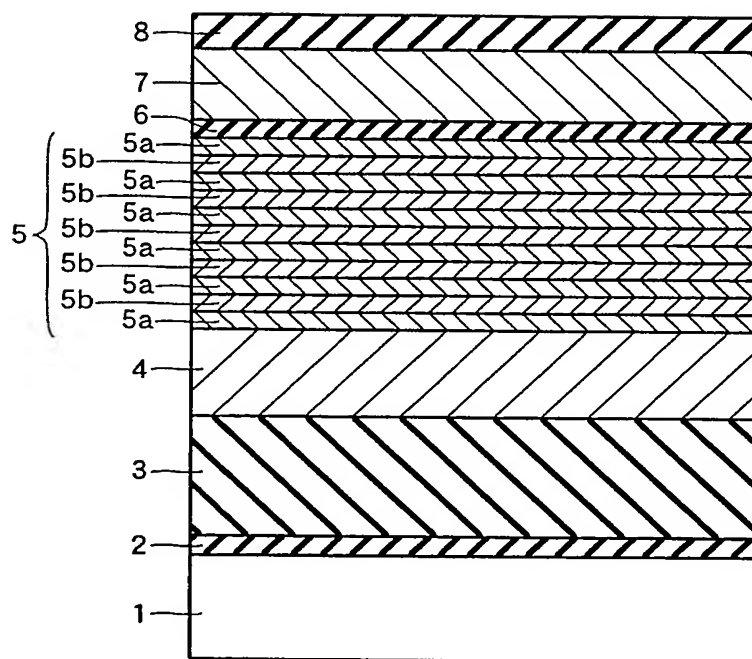


FIG.5

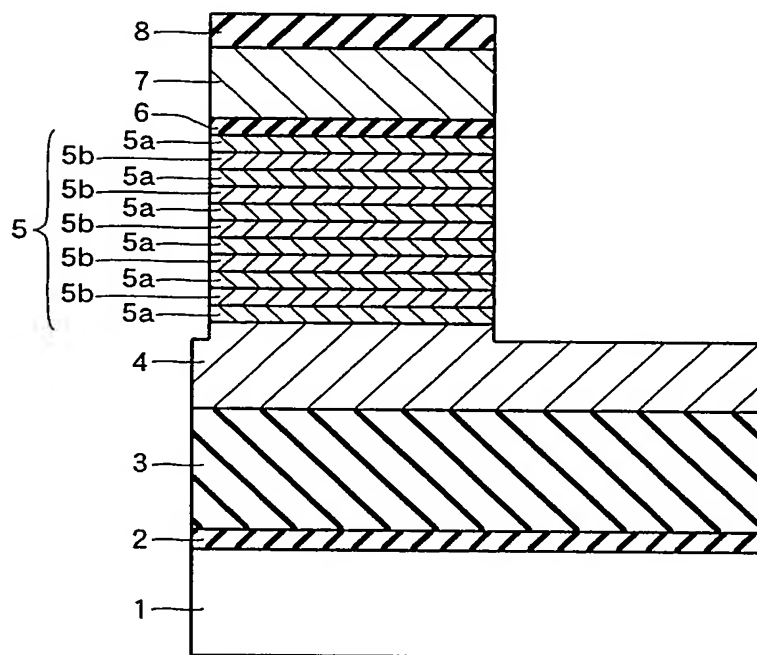


FIG. 6

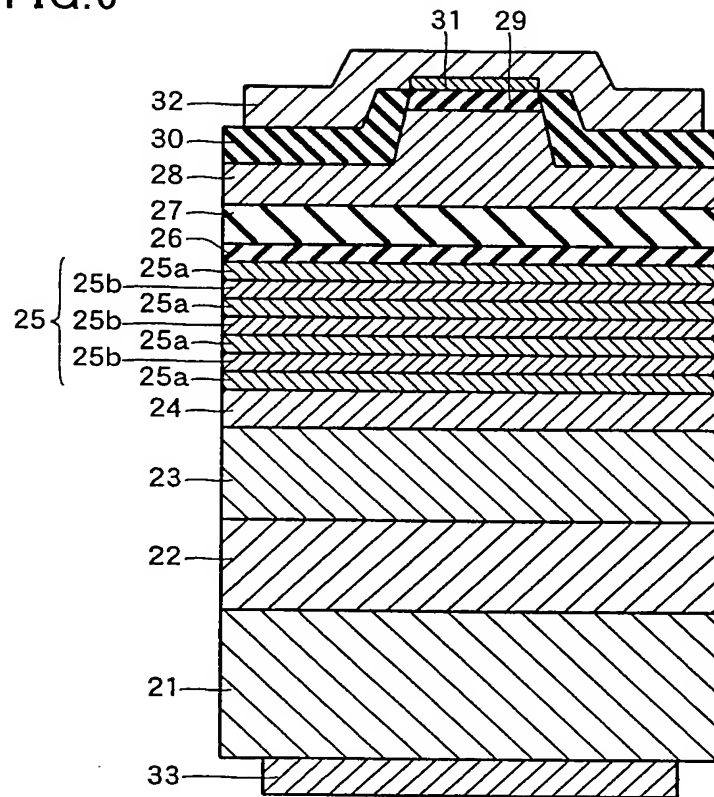


FIG. 7

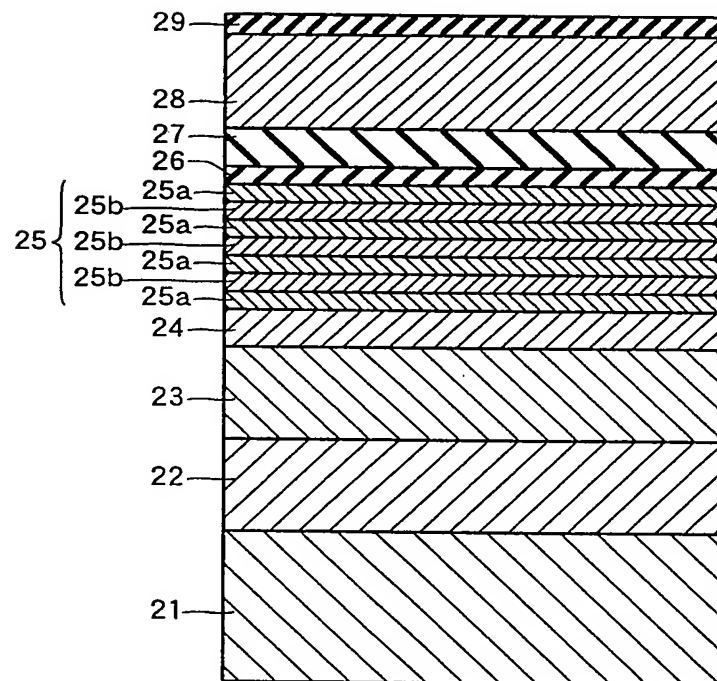


FIG.8

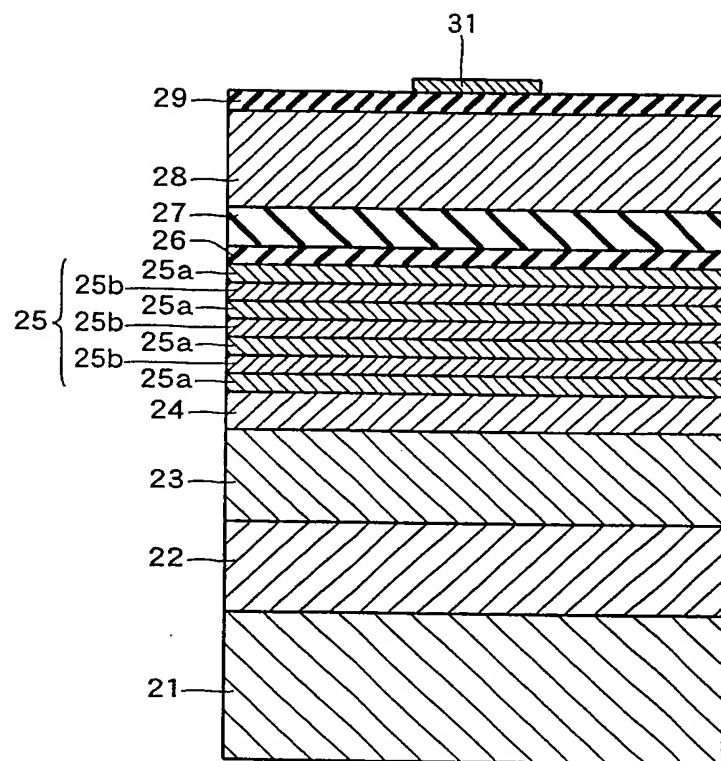


FIG.9

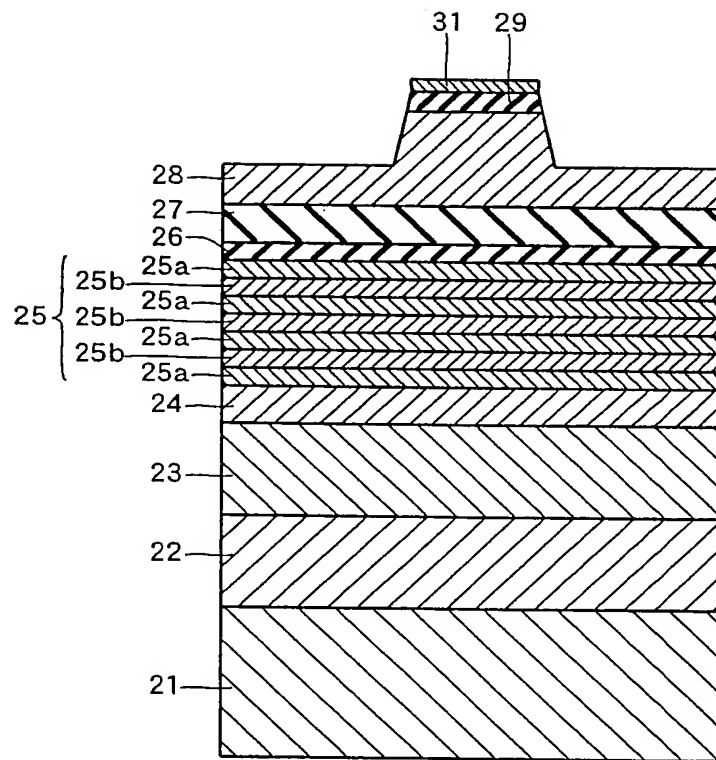


FIG.10

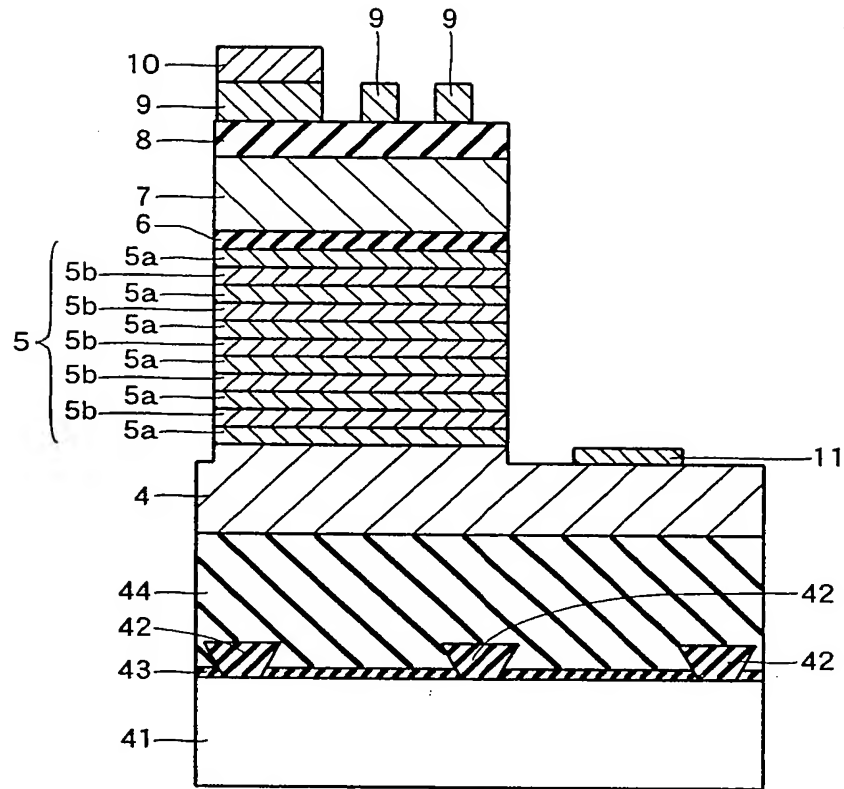


FIG.11

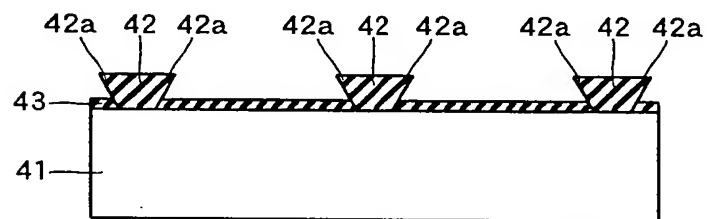


FIG.12

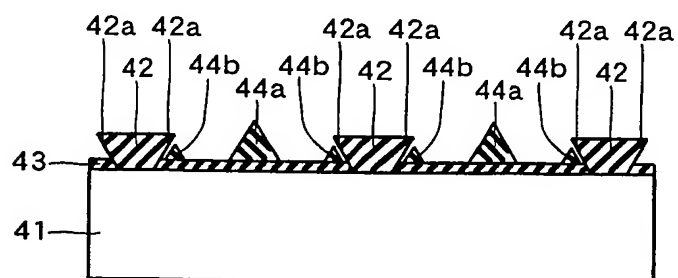
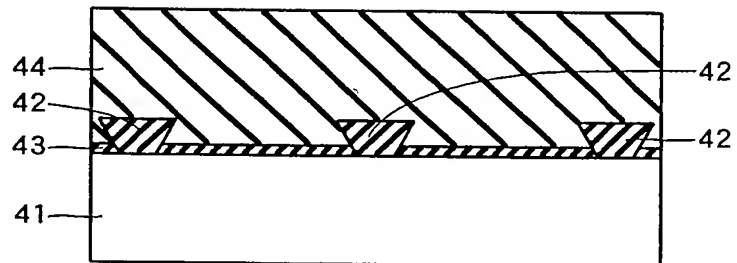


FIG.13



4  
9  
  
[Document Name] Abstract

[Abstract]

[Subject] A nitride-based semiconductor device capable of improving luminous efficiency by reducing light absorption  
5 loss in a contact layer is provided.

[Solving Means] This nitride-based semiconductor light-emitting device comprises an n-type contact layer 4 formed on a sapphire substrate 1, an MQW active layer 5, formed on the n-type contact layer 4, consisting of a nitride-based semiconductor layer, a p-type cladding layer 7  
10 formed on the MQW active layer 5, an undoped contact layer 8 formed on the p-type cladding layer 7 and a p-side electrode formed on the undoped contact layer 8.

[Selected Drawing] Fig. 1

15

Patent Application No. 2002-271968

Applicant Record

Identification No. [000001889]

1. Date of Alternation October 20, 1993

[Reason(s) of Alternation] Alternation of Address

Address 2-5-5, Keihan Hondori,

Moriguchi-shi, Osaka

Name SANYO ELECTRIC., LTD.

Certification No. 2003-3053262